



# An intelligent Fusion Framework for Risk Assessment of Autonomous Ship through Functional Mapping Criterion Sub-Intervals into Single Interval Method

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## Abstract

Nowadays, intelligent information technology can implement high-level information processing and decision-making activities that can support risk assessment of autonomous. Risk assessment is a critical process for deploying autonomous ships, ensuring these innovative vessels' safe and efficient operation. There is a need to identify, analyze, and mitigate potential risks associated with system reliability, collision avoidance, cybersecurity, environmental conditions, human interaction, regulatory compliance, sensor performance, data integrity, emergency response, and testing and validation. This work provides an overview of the essential considerations and objectives of risk assessment in autonomous boats. We used the multi-criteria decision-making model to deal with various criteria. The Ranking of Alternatives through Functional Mapping Criterion Sub-Intervals into Single Interval (RAFSI) method is applied to rank the alternatives. We used the ten criteria and twenty options in this study. The results show that the proposed framework can provide a comprehensive risk assessment framework that can enable stakeholders to gain insights into potential hazards and vulnerabilities unique to autonomous ships.

**Keywords:** Multi-Criteria Decision-Making (MCDM); Information Systems (IS); Information Technology (IT); Internet of things (IoT); Artificial Intelligence (AI)

## 1. Introduction

The emergence of autonomous ships, driven by advancements in artificial intelligence, robotics, and maritime technology, is poised to revolutionize the shipping industry. As these autonomous vessels navigate the world's oceans, assessing and managing the risks associated with their operations becomes imperative. Risk assessment in autonomous ships involves identifying, analyzing, and evaluating potential hazards and vulnerabilities to ensure this transformative technology's safe and efficient deployment [1], [3]. Risk assessment in autonomous ships is an iterative process that requires continuous monitoring, evaluation, and improvement. As the technology evolves and new risks emerge, ongoing risk assessments help identify and address these growing challenges, ensuring that safety remains a top priority throughout the life cycle of autonomous ships. This assessment evaluates system reliability and redundancy, collision avoidance capabilities, cybersecurity vulnerabilities, environmental considerations, human interaction protocols, compliance with regulations, sensor performance, data integrity, emergency response procedures, and testing and validation processes. This knowledge enables stakeholders to make informed decisions, implement appropriate risk mitigation measures, and develop robust safety protocols to ensure the safe operation of autonomous vessels [4], [5].

Risk assessment in autonomous ships aims to systematically identify and analyze potential risks that may arise during the vessel's operation and to develop strategies to mitigate those risks effectively. There is a need to identify, analyze, and mitigate potential risks associated with system reliability, collision avoidance, cyber security, environmental conditions, human interaction, regulatory compliance, sensor performance, data integrity, emergency response, and testing and validation. So, this study aims to apply the functional mapping criterion sub-intervals into a single interval method for risk assessment and evaluate the alternatives. We used the ten criteria and twenty options in this study. They show that the proposed framework can provide a comprehensive risk assessment framework that can enable stakeholders to gain insights into potential hazards and vulnerabilities unique to autonomous ships.

The MCDM gives decision-makers the freedom to choose the course of action that most closely fits their preferences, priorities, and the particulars of the problem. This method recognizes the inherent complexity of choices made in the real world, where a wide range of elements with varied degrees of relevance affects the final results. MCDM may help organizations make wise choices and has many applications [10], [11]. The procedure includes organizing the issue, obtaining pertinent information, establishing standards, contrasting potential solutions, and ultimately choosing the best option via a systematic assessment. The MCDM framework assesses and compares options according to how effectively they function about a range of criteria. Each criterion has a weight that represents its relative importance [12].

This work is arranged as follows: the first section gives the introduction; the second section introduces the autonomous ships from information systems viewpoint; the third section discusses the related work; the fourth section describes the criteria for risk assessment of autonomous ships; the fifth section introduces the proposed ranking of alternatives through functional mapping criterion sub-intervals into single interval method; the sixth section applies the proposed method with numerical examples. The seventh section discusses the results; the eighth section represents the conclusion of this work.

## 2. Autonomous Ships from Information Fusion Systems Viewpoints

Intelligent information technology is an underlying technology that implements high-level information processing activities cognition, learning, reasoning, and decision making. Intelligent information systems provides technologies that can support risk assessment of autonomous ships such as the Internet of Things (IoT), cloud computing, big data analytics, and data security as follows:

- **The Internet of Things (IoT)**

The IoT means that things are connected to the internet. It has been applied to maximize the safety of autonomous ships. The IoT involves autonomous navigation, cloud connectivity, and operator interaction, and connects ships to everything.

- **Cloud Computing**

The cloud computing service provides systems of ships with the IT resources that they need anytime and anywhere via wired and wireless mobile terminals and the internet, which is attracting attention as a key industry.

- **Big Data Analytics.**

The characteristics of the data recorded in association with all activities between people and things are that the volume is large. The smart autonomous ship architecture needs to analyze the status of ships and the other activities

- **Data Security**

Data security involves authentication and information protection and prevention of infringement of IT devices installed on autonomous ships. Second, it prevents the encryption and forgery of data in the wireless connections between autonomous ships and data centers.

## 3. Related work

Risk assessment is a fundamental aspect of deploying autonomous ships safely and efficiently. By systematically evaluating and mitigating potential risks, stakeholders can confidently navigate the complexities of independent ship operations. With practical risk assessment and management practices in place, autonomous ships have the potential to revolutionize the maritime industry, offering increased efficiency, reduced environmental impact, and enhanced safety in global marine transportation [13]–[15]. Risk assessment also plays a crucial role in building trust and confidence in autonomous ship technology. It provides a framework for assessing and addressing potential risks associated with the technology, vital for regulatory compliance, insurance considerations, stakeholder confidence, and public acceptance [16]–[18].

Autonomous ships operate without direct human intervention, relying on sophisticated sensors, algorithms, and control systems to navigate, make decisions, and carry out various tasks. While these technological advancements offer numerous benefits, including improved operational efficiency and reduced human error, they also introduce new challenges and risks that must be addressed [19]–[22].

There many researchers attempt to address the challenges of decision-making problems and handle risk assessment of autonomous ship to addresses dimensions of risks that face ships. Zhang et al [36] apply a fuzzy bayesian network for analyzing risks of unmanned ships in inland rivers. Akyildiz and Mentis [35] integrated Fuzzy Set with analytic hierarchy process for managing risk and decision-making process. Cheng et al [37] use a fuzzy multi-criteria method to choose suitable ferry operator. Koohathongsumrit [38] combines MCDM, fuzzy risk assessment model (FRAM), and data envelopment analysis (DEA) for determining the suitable route in multimodal transportation networks. Liao et al [39] addressed 195 articles that have been published from 2007 to 2022 to enhance the accuracy of decision-making, also this work, handle the progress of using interval analysis techniques and fuzzy extensions in MCDM problems.

A thorough theoretical framework, including criteria, kinds, techniques, and the decision-making process, is provided by decision theory. Concurrent with its increasing acknowledgment in several fields, there has been a noteworthy upsurge in decision-making research in the last few years. MCDM is a decision-making methodology that facilitates identifying or prioritizing the optimal options in scenarios with several choices and conflicting criteria. By using a variety of criteria instead of just one, the method enables decision-makers to assess and balance options [6]–[8].

It is often used when there are several competing goals and complicated decision-making. MCDM techniques consider various issues, such as economic, environmental, social, and technological concerns, to guarantee a logical and systematic approach to decision-making. The main goal of MCDM is to provide decision-makers with a range of workable options rather than only addressing problems with decision-making. Put differently, MCDM seeks to offer various viable solutions that consider different criteria or elements related to a particular issue rather than just identifying the one correct answer to a decision problem [9].

#### 4. Criteria for Risk Assessment of Autonomous Ship

Risk assessment should include an evaluation of the testing protocols, simulation models, and validation processes to verify the performance and safety of the autonomous systems. The criteria in this study are described as:

1. **System Reliability and Redundancy:** Autonomous ships must have reliable and redundant systems to minimize the risk of system failures. The risk assessment should evaluate the robustness and redundancy of critical components such as sensors, control systems, communication systems, and power systems.
2. **Cyber security:** Autonomous ships are vulnerable to cyber threats, including hacking, malware, and unauthorized access. Risk assessment should include cybersecurity evaluations, addressing potential vulnerabilities, and implementing safeguards to protect against cyber-attacks.
3. **Collision Avoidance:** Collision avoidance is a critical aspect of autonomous ship operations. Risk assessment should evaluate the effectiveness of collision avoidance systems and algorithms, considering sensor accuracy, response time, decision-making capabilities, and interaction with other vessels and objects in the maritime environment.
4. **Environmental Conditions:** Autonomous ships must operate safely in various environmental conditions, such as rough seas, fog, and adverse weather. Risk assessment should consider the ship's ability to handle challenging conditions and the potential risks associated with such environments.
5. **Human Interaction and Intervention:** Although autonomous ships operate without human intervention, there should be provisions for human interaction and intervention in emergencies or unforeseen situations. Risk assessment should evaluate the effectiveness of communication systems and protocols for human intervention when necessary.
6. **Compliance with International Regulations:** Autonomous ships must comply with international maritime regulations and standards. Risk assessment should include a thorough evaluation of the ship's compliance with safety, navigation, communication, and environmental protection regulations.

7. **Sensor Performance and Accuracy:** Autonomous ships rely on various sensors, such as radar and cameras, for perception and situational awareness. Risk assessment should assess the performance and accuracy of these sensors, considering factors such as range, resolution, detection capabilities, and potential limitations.
8. **Data Integrity and Processing:** Autonomous ships generate and process vast amounts of data in realtime. Risk assessment should evaluate the integrity of sensor data, ensuring accurate and reliable information for decision-making processes.
9. **Emergency Response and Contingency Plans:** Autonomous ships should have well-defined emergency response procedures and contingency plans for system failures, accidents, or other critical situations. Risk assessment should evaluate the adequacy and effectiveness of these plans, including communication protocols, backup systems, and crew coordination.
10. **Testing and Validation:** Rigorous testing and validation procedures are essential for ensuring the safety and reliability of autonomous ships.

**5. The proposed ranking of Alternatives through Functional Mapping Criterion Sub-Intervals into Single Interval Method**

This section introduces the proposed model[23]–[28] as shown in Figure 1.

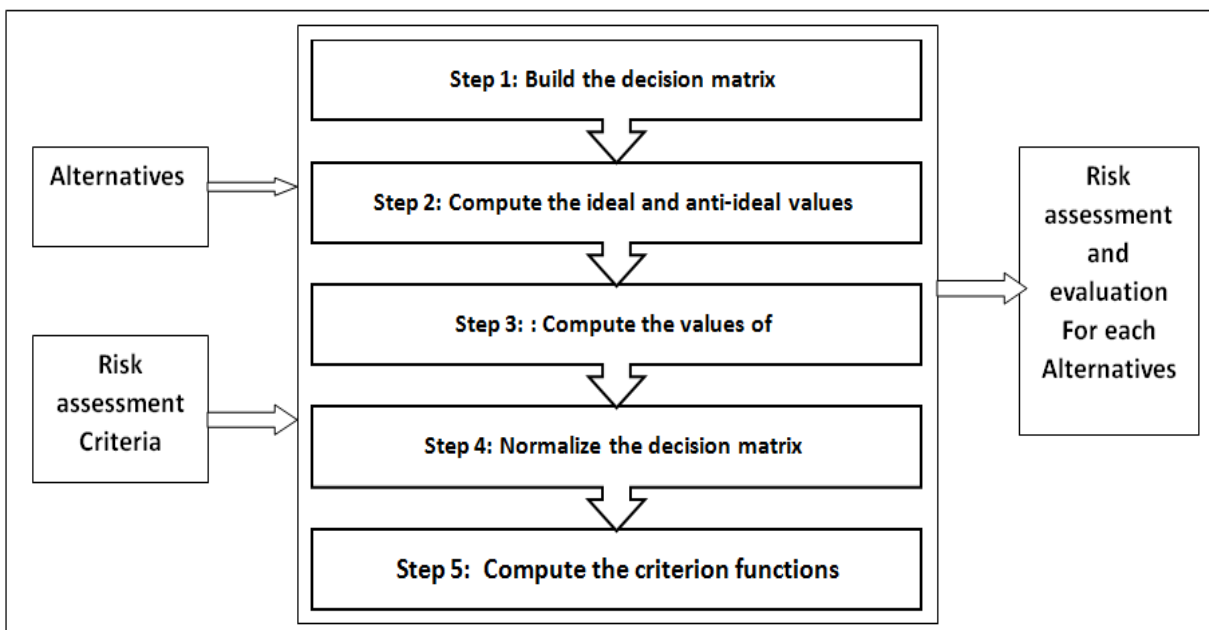


Figure 1: The steps of the proposed method

**Discussion of the proposed framework:**

The proposed framework consists of five steps the output of each step is taken as input to the next step. The proposed framework applies functional mapping criterion sub-intervals into single interval method to rank alternatives. The proposed framework involves decision-making process that facilitates risk assessment of autonomous ship

The decision-making process of the proposed framework assesses and compares options according to how effectively they function about a range of criteria. Each criterion has a weight that represents its relative importance. Each step of the proposed framework is applied as the following:

**Step 1:** Build the decision matrix [29]

$$x = \begin{bmatrix} x_{11} & \dots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \dots & x_{mn} \end{bmatrix} \tag{1}$$

**Step 2:** Compute the ideal and anti-ideal values

$$C_j \begin{cases} \max x_{ij} \\ \min x_{ij} \end{cases} \tag{2}$$

**Step 3:** Compute the values of  $F_A(C_j)$

$$F_A(C_j) = D_{ij} = \frac{6 - 1}{\max x_{ij} - \min x_{ij}} x_{ij} + \frac{\max x_{ij} * 1 - \min x_{ij} * 6}{\max x_{ij} - \min x_{ij}} \tag{3}$$

**Step 4:** Normalize the decision matrix

$$Z_{ij} = \frac{D_{ij}}{2 \left( \frac{6+1}{2} \right)} \tag{4}$$

$$Z_{ij} = \frac{\left( \frac{2}{\frac{1+1}{1+6}} \right)}{2D_{ij}} \tag{5}$$

**Step 5:** Compute the criterion functions.

$$G_i = \sum_{j=1}^n w_j Z_{ij} \tag{6}$$

## 6. Applying the proposed model with a numerical example

We used the ten criteria and 20 alternatives in this study. The criteria in this study are described as:

1. System Reliability and Redundancy
2. Cybersecurity
3. Collision Avoidance
4. Environmental Conditions
5. Human Interaction and Intervention
6. Compliance with International Regulations
7. Sensor Performance and Accuracy
8. Data Integrity and Processing
9. Emergency Response and Contingency Plans
10. Testing and Validation

**Step 1:** Build the decision matrix by Eq. (1). The experts used a scale between 1 and 9 to evaluate the criteria and alternatives.

**Step 2:** Compute the ideal and anti-ideal values by Eq. (2)

**Step 3:** Compute the values of  $F_A(C_j)$  as shown in Table 1. By Eq. (3)

Table 1: The values of  $F_A(C_j)$ .

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$ACC_1$	$ACC_2$	$ACC_3$	$ACC_4$	$ACC_5$	$ACC_6$	$ACC_7$	$ACC_8$	$ACC_9$	$ACC_{10}$
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ACA <sub>11</sub>	ACA <sub>10</sub>	ACA <sub>9</sub>	ACA <sub>8</sub>	ACA <sub>7</sub>	ACA <sub>6</sub>	ACA <sub>5</sub>	ACA <sub>4</sub>	ACA <sub>3</sub>	ACA <sub>2</sub>	ACA <sub>1</sub>
6	5.285714	4.571429	2.428571	1	1.714286	3.857143	3.142857	6	5.285714	1
4.571429	3.142857	3.857143	1.714286	3.142857	1	3.857143	6	5.285714	3.857143	1.714286
5.166667	4.333333	1.833333	5.166667	6	5.166667	6	5.166667	3.5	1.833333	1
3.142857	1	1.714286	3.142857	1	3.857143	6	3.857143	3.142857	5.285714	4.571429
1	2.428571	3.142857	3.857143	6	5.285714	6	3.142857	5.285714	4.571429	6
2.428571	4.571429	3.142857	1	3.857143	3.142857	5.285714	3.857143	6	2.428571	6
1	3.142857	6	5.285714	4.571429	2.428571	3.142857	1	3.142857	3.142857	5.285714
3.142857	5.285714	3.857143	3.142857	1	3.142857	5.285714	6	3.857143	3.857143	4.571429
3.857143	3.142857	2.428571	1	3.857143	3.142857	4.571429	5.285714	6	1.714286	2.428571
4.571429	2.428571	5.285714	3.142857	3.857143	3.142857	5.285714	6	5.285714	1	3.142857

ACA <sub>12</sub>	5.285714	3.142857	3.142857	1	3.857143	5.285714	3.142857	4.571429	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857
ACA <sub>13</sub>	3.142857	1	3.5	6	3.857143	3.142857	3.142857	4.571429	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857
ACA <sub>14</sub>	1	1.714286	2.666667	5.285714	3.142857	5.285714	5.285714	4.571429	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857
ACA <sub>15</sub>	3.142857	3.857143	1	4.571429	5.285714	3.142857	3.142857	4.571429	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857
ACA <sub>16</sub>	3.857143	6	4.333333	5.285714	6	3.857143	3.857143	4.571429	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857
ACA <sub>17</sub>	5.285714	5.285714	5.166667	4.571429	2.428571	5.285714	5.285714	4.571429	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857
ACA <sub>18</sub>	4.571429	3.142857	6	5.285714	3.857143	2.428571	3.142857	4.571429	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857
ACA <sub>19</sub>	2.428571	4.571429	5.166667	3.142857	5.285714	6	3.857143	4.571429	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857
ACA <sub>20</sub>	6	3.142857	5.166667	3.857143	3.142857	2.428571	4.571429	5.285714	2.428571	3.857143	6	4.571429	5.166667	3.142857	3.142857	3.142857	3.142857	3.142857	3.142857

**Step 4:** Normalize the decision matrix by Eqs. (4 and 5) as shown in Table 2.

Table 2: The normalization decision matrix

ACC <sub>1</sub>	ACC <sub>2</sub>	ACC <sub>3</sub>	ACC <sub>4</sub>	ACC <sub>5</sub>	ACC <sub>6</sub>	ACC <sub>7</sub>	ACC <sub>8</sub>	ACC <sub>9</sub>	ACC <sub>10</sub>
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	ACA <sub>1</sub>	ACA <sub>2</sub>	ACA <sub>3</sub>	ACA <sub>4</sub>	ACA <sub>5</sub>	ACA <sub>6</sub>	ACA <sub>7</sub>	ACA <sub>8</sub>	ACA <sub>9</sub>	ACA <sub>10</sub>	ACA <sub>11</sub>
	0.142857	0.755102	0.857143	0.44898	0.55102	0.244898	0.142857	0.346939	0.653061	0.755102	0.857143
	0.244898	0.55102	0.755102	0.857143	0.55102	0.142857	0.44898	0.244898	0.55102	0.44898	0.653061
	0.142857	0.261905	0.5	0.738095	0.857143	0.738095	0.857143	0.738095	0.261905	0.619048	0.738095
	0.653061	0.755102	0.44898	0.55102	0.857143	0.55102	0.142857	0.44898	0.244898	0.142857	0.44898
	0.857143	0.653061	0.755102	0.44898	0.857143	0.755102	0.857143	0.55102	0.44898	0.346939	0.142857
	0.857143	0.346939	0.857143	0.55102	0.755102	0.44898	0.55102	0.142857	0.44898	0.653061	0.346939
	0.755102	0.44898	0.44898	0.142857	0.44898	0.346939	0.653061	0.755102	0.857143	0.44898	0.142857
	0.653061	0.55102	0.55102	0.857143	0.755102	0.44898	0.142857	0.44898	0.55102	0.755102	0.44898
	0.346939	0.244898	0.857143	0.755102	0.653061	0.44898	0.55102	0.142857	0.346939	0.44898	0.55102
	0.44898	0.857143	0.755102	0.857143	0.755102	0.44898	0.55102	0.44898	0.55102	0.755102	0.755102
	0.653061	0.244898	0.755102	0.44898	0.653061	0.44898	0.55102	0.142857	0.346939	0.44898	0.653061
	0.857143	0.142857	0.44898	0.55102	0.755102	0.44898	0.55102	0.44898	0.55102	0.346939	0.857143

<b>ACA<sub>12</sub></b>	0.755102	0.44898	0.857143	0.55102	0.244898	0.55102	0.857143	0.55102	0.857143	0.55102	0.244898	0.755102
<b>ACA<sub>13</sub></b>	0.44898	0.142857	0.5	0.857143	0.55102	0.857143	0.755102	0.857143	0.755102	0.857143	0.142857	0.244898
<b>ACA<sub>14</sub></b>	0.142857	0.244898	0.380952	0.755102	0.44898	0.755102	0.44898	0.755102	0.44898	0.755102	0.44898	0.55102
<b>ACA<sub>15</sub></b>	0.44898	0.55102	0.142857	0.653061	0.755102	0.44898	0.142857	0.44898	0.142857	0.653061	0.55102	0.755102
<b>ACA<sub>16</sub></b>	0.55102	0.857143	0.619048	0.755102	0.857143	0.55102	0.55102	0.55102	0.346939	0.857143	0.857143	0.857143
<b>ACA<sub>17</sub></b>	0.755102	0.755102	0.738095	0.653061	0.346939	0.755102	0.142857	0.44898	0.44898	0.755102	0.755102	0.755102
<b>ACA<sub>18</sub></b>	0.653061	0.44898	0.857143	0.755102	0.55102	0.346939	0.44898	0.142857	0.44898	0.44898	0.44898	0.44898
<b>ACA<sub>19</sub></b>	0.346939	0.653061	0.738095	0.44898	0.755102	0.857143	0.55102	0.55102	0.55102	0.55102	0.55102	0.653061
<b>ACA<sub>20</sub></b>	0.857143	0.44898	0.738095	0.55102	0.44898	0.346939	0.653061	0.755102	0.857143	0.857143	0.142857	0.857143

We compute the weights of criteria by the average method as shown in Figure 2.

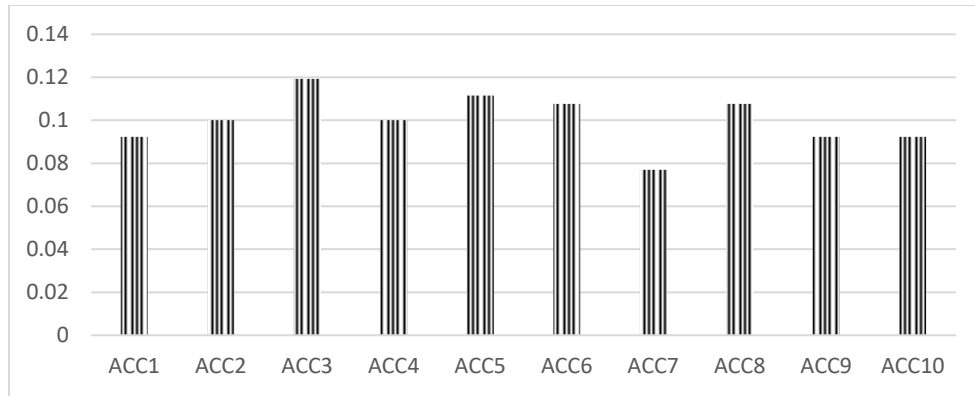


Figure 2: The criteria weights in risk assessment in autonomous ship

**Step 5:** Compute the criterion functions by Eq. (6) as shown in Figure 3.

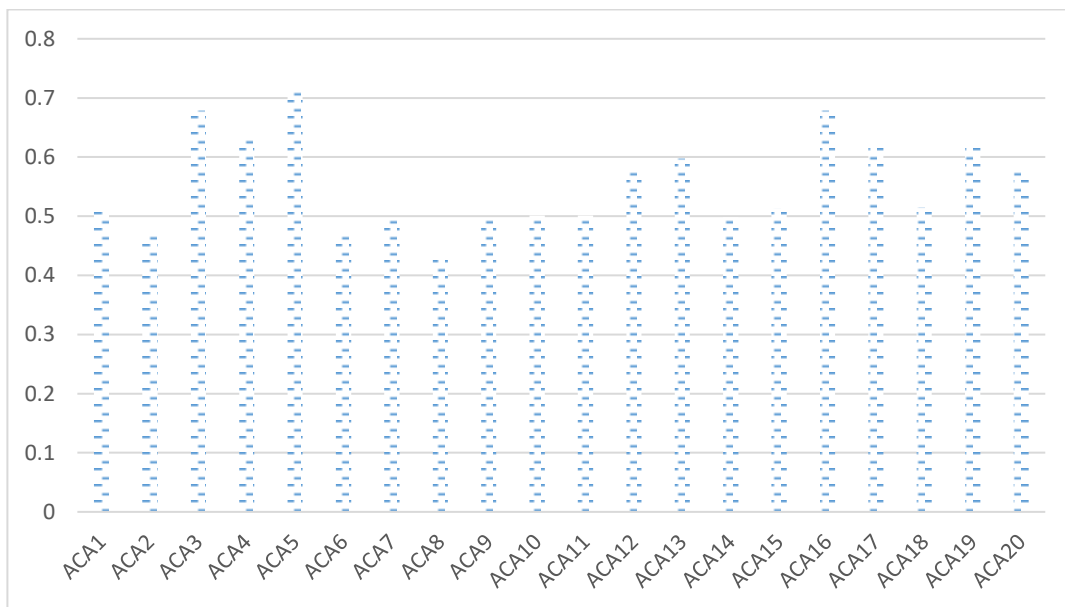


Figure 3: The rank of risks

We change the weights of criteria to show the different ranks of alternatives. We suggested ten cases in changing the weights of criteria as shown in Figure 4. We put one criterion with 0.12 weight and all criteria are equal. Then compute the rank of alternatives as shown in Figure 5. The results show the ranks are stable.

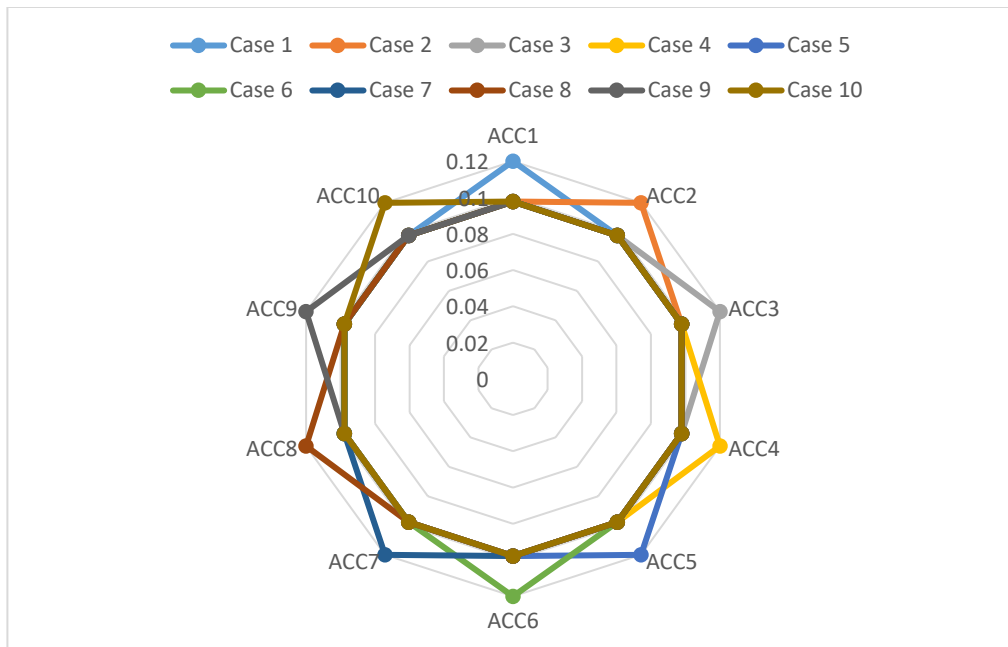


Figure 4: The ten cases in weights of criteria

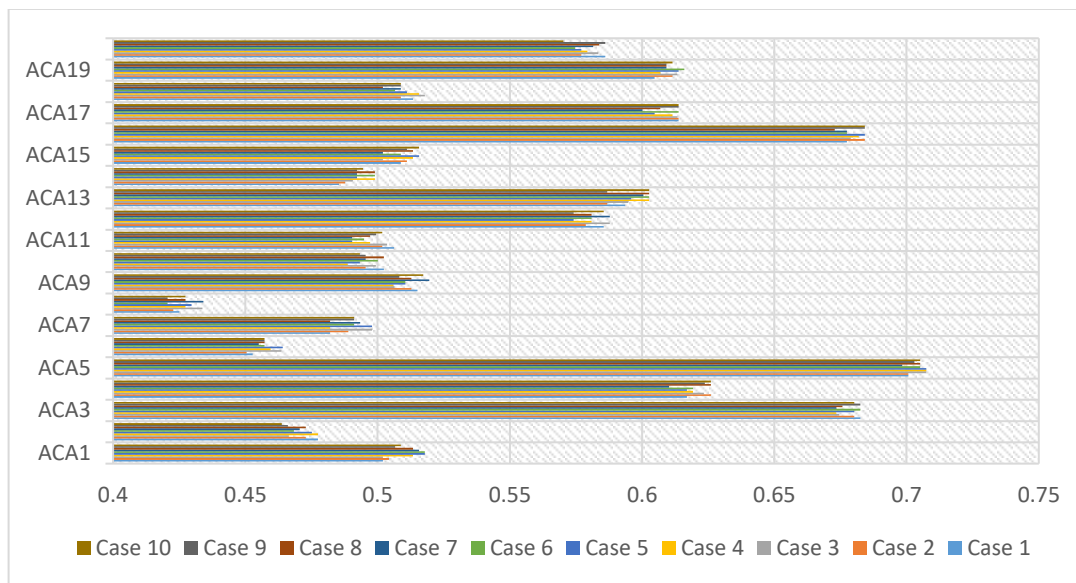


Figure 5: The rank of alternatives under ten cases

**7. Results and Discussions**

The results indicated that the proposed method can evaluate alternatives based on the risk assessment criteria of each alternative. We used the 10 criteria and 20 alternatives in this study. The weights of the risks are computed. Then, the alternatives are ranked. The results show that the proposed method can introduce a more simple and flexible method that can handle any number of criteria and alternatives that give more reliability to results. The systematic evaluation of factors such as system reliability, collision avoidance capabilities, cybersecurity vulnerabilities, environmental considerations, human interaction protocols, regulatory compliance, sensor performance, data integrity, emergency

response procedures, and testing and validation processes[30]–[32], risks associated with autonomous ship operations can be effectively identified and mitigated. Implementing risk assessment practices contributes to building trust and confidence in autonomous ship technology. It demonstrates a commitment to safety, enabling regulatory compliance, facilitating insurance considerations, gaining stakeholder confidence, and fostering public acceptance. Furthermore, risk assessment in autonomous ships is an iterative and dynamic process. As technology evolves, new risks may arise, requiring continuous monitoring, evaluation, and improvement. Ongoing risk assessments are crucial for identifying and addressing emerging challenges, ensuring that safety remains a top priority throughout the life cycle of autonomous ships[33], [34]. By conducting robust risk assessments, stakeholders can develop effective risk mitigation strategies, build trust, and ensure the safe integration of autonomous ships into the maritime industry.

## 8. Conclusions

Risk assessment is vital in successfully deploying autonomous ships, enabling stakeholders to identify and address potential risks to ensure safe and efficient operations. By conducting comprehensive risk assessments and implementing appropriate risk mitigation measures, stakeholders can confidently navigate the complexities of autonomous ship operations. Integrating autonomous ships into the maritime industry can enhance operational efficiency, reduce environmental impact, and improve safety in global marine transportation. The vision of safe and efficient independent ship operations can be realized through practical risk assessment and management practices. We used the MCDM method to analyze the criteria of autonomous ships. The RAFSI method was applied to rank the risks. We used the 10 criteria and 20 alternatives in this study. The results indicated that the proposed framework could provide a comprehensive risk assessment framework that can enable stakeholders to gain insights into potential hazards and vulnerabilities unique to autonomous ships.

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